EVA HAZARDS DUE TO TPS INSPECTION AND REPAIR

C. E. Stewart[(1)]

[(1)]*Science Applications International Corporation , 2450 NASA Parkway, Houston, TX 77058, USA, Email:christine.e.stewart@mail.nasa.gov*

ABSTRACT

Tile inspection and repair activities have implicit hazards associated with them. When an Extra Vehicular Activities (EVA) crewmember and associated hardware are added into the equation, additional hazards are introduced. Potential hazards to the Extravehicular Mobility Unit (EMU), the Orbiter or the crew member themselves are created. In order to accurately assess the risk of performing a TPS inspection or repair, an accurate evaluation of potential hazards and how adequately these hazards are controlled is essential.

The EMU could become damaged due to sharp edges, protrusions, thermal extremes, molten metal or impact with the Orbiter. Tools, tethers and the presence of a crew member in the vicinity of the Orbiter Thermal Protection System (TPS) pose hazards to the Orbiter. Hazards such as additional tile or Reinforced Carbon-Carbon (RCC) damage from a loose tool, safety tethers, crewmember or arm impact are introduced. Additionally, there are hazards to the crew which should be addressed. Crew hazards include laser injury, electrical shock, inability to return to the airlock for EMU failures or Orbiter rapid safing scenarios, as well as the potential inadvertent release of a crew member from the arm/boom.

The aforementioned hazards are controlled in various ways. Generally, these controls are addressed operationally versus by design, as the majority of the interfaces are to the Orbiter and the Orbiter design did not originally account for tile repair. The Shuttle Remote Manipulator System (SRMS), for instance, was originally designed to deploy experiments, and therefore has insufficient design controls for retention of the Orbiter Boom Sensor System (OBSS).

Although multiple methods to repair the Orbiter TPS exist, the majority of the hazards are applicable no matter which specific repair method is being performed. TPS Inspection performed via EVA also presents some of the same hazards. Therefore, the hazards common to all TPS inspection or repair methods will be addressed.

1. TPS Inspection and Repair Methods

1.1. Inspection

Nominally, on-orbit inspection of Orbiter TPS is performed by the Laser Dynamic Range Imager (LDRI), the Laser Camera System (LCS), and the Intensified Television Camera (ITVC). All of these sensors are located on the end of the OBSS, which is a 50-foot long boom that may be grasped and moved by the Orbiter's Shuttle Remote Manipulator System (SRMS) (robot arm), and does not normally involve EVA crew. However, should a failure occur, or the Mission Management Team (MMT) decide it is necessary, an EVA crewmember may be sent to perform a visual inspection or take digital images for a photogrammetry assessment.

Depending on the location of the potential damage site, the EVA crew may be on the end of the SRMS or may have to ingress an articulating portable foot restraint on the end of the OBSS. Potential scenarios of EVA inspection include up to 3 inspections of specific potential damage sites, or a complete visual/photographic examination of the Orbiter wing-leading edge. Either scenario involves similar initial tasks of setting up for ingress into the articulating portable foot restraint (APFR) on the RMS or the OBSS. The robotic arms are used to manuever the crew to the locations necessary for taking digital photographs. After photography is complete, the crew is manuevered back to the payload bay sill for egress from the APFR and clean-up for return to the airlock. Normally, for TPS inspection, the EVA crew is at least five feet away from the TPS, generally more than ten feet. These EVA tasks can take as little as 4 hours for a single inspection point, or 7 hours if the entire wing-leading edge of the Orbiter is being inspected EVA.



Figure 1. SRMS/OBSS on STS-114

1.2. Repair

TPS repair options are only achievable EVA. TPS repair options include use of the shuttle tile ablator-54 (STA-54) material, emittance wash, or tile overlay system for tile repair, and either non-oxide adhesive experimental (NOAX) material or an RCC plug for RCC repair. Any of these options involve the use of specialized EVA tools (see Figure 2 and 3), as well as proximity to the Orbiter TPS.



Figure 2. Example RCC repair tools[1]

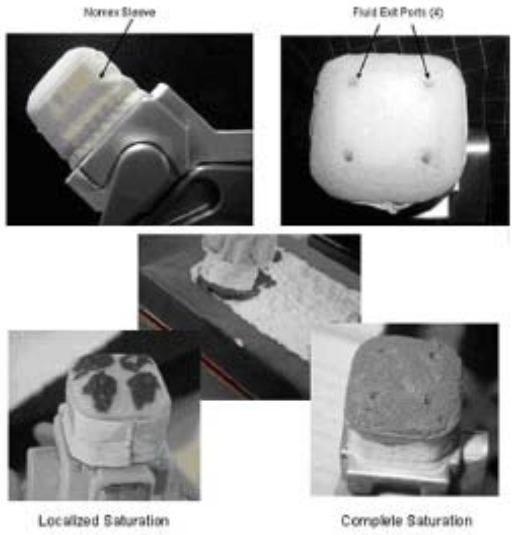


Figure 3. Emmittance Wash Applicator[1]

Also, all repair options involve tasks that are estimated to last at least six hours. If the location of the repair is far enough back on the bottom of the Orbiter, then the use of the OBSS is required for the EVA crew to perform a repair. If the OBSS is not required, then the SRMS or the Space Station Remote Manipulator System (SSRMS) may be used as a worksite platform. Use of the SSRMS is obviously only possible while the Orbiter is docked to the ISS. So, for repair options as well as for EVA Inspection, the EVA worksite platform will be either the OBSS or one of the robotic arms.

During flight STS-114, the EVA crew performed a removal of a TPS gap-filler. The location of the gap-filler was far enough forward on the Orbiter that the SSRMS was used as the EVA worksite platform for this operation. A detailed test objective (DTO) was performed during EVA 1 for STS-121 to determine the flexibility of the OBSS under EVA loading conditions. As a result of these two EVA tasks, the generic EVA hazards associated with TPS Inspection and Repair have been assessed and controls have been identified by the Shuttle and Station programs.

2. EMU Hazards

The most common EVA hazards are those applicable to the EMU. Because the suit can be considered an independent space vehicle, which provides life support to the crewmember, damage to the suit can be life-threatening.

2.1. Sharp Edges

One of the most common EVA hazards is puncture of the suit due to sharp edges, burrs, corners, etc. While the EMU has a secondary oxygen supply in the case of a leak, that supply is designed based on a very small puncture size. Therefore, any puncture to the suit greater than a quarter inch would result in a loss of crew. Even a pin-hole puncture will result in the return of the crew to the habitable environment, with subsequent loss of the EVA task. Therefore, it is important to assess the EVA worksite and tools involved in the TPS Inspection/Repair task to ensure all potential sharp edges are adequately controlled.

Most of the hardware utilized in an EVA Inspection or TPS repair has been assessed and verified to not be a puncture hazard. Unfortunately, due to design constraints, some hardware was identified with sharp edges. Examples of such hardware are the LDRI baffle, the electrical flight-releasable grapple fixture (EFGF) grapple release, and the Integrated Boom Assembly (IBA) grapple fixture cam arms.

In the case of the LDRI baffle, the small ledges at the sensor aperture area do no meet the requirements of rounding to prevent a sharp edge hazard. The crew is trained to know where this area is, and avoid touching this area with the EMU glove. The area of concern is too small for anything other than a gloved finger to access. The crew also has a warning in the procedures to avoid contact with the baffle.

Neither the EFGF grapple fixture, nor the cam arms are contacted nominally by the EVA crew during an Inspection or Repair. The crew is cautioned about the areas during TPS training to avoid these areas. The

crew is also cautioned during training about some hardware that is a concern for use in other EVA tasks that they may be exposed to during an inspection or repair EVA. These include SRMS joint hard stops, electrical connectors, and the inside of the worksite interface fixture (WIF). In all cases, the program has accepted the risk of sharp edges with the assurance of the crew and the operations personnel that these items are avoidable during EVA operations.

In addition, RCC and tile were assessed to see if either were a sharp edge hazard. The assessment performed identified damaged RCC and tile as the most likely to be a sharp edge hazard. While the tile and RCC did not meet rounding requirements, the analysis and test performed showed that the damaged RCC and tile would break or compress prior to damaging the EMU.

2.2. Touch Temperature

In the EVA environment, thermal extremes are a primary consideration. Contact by an EVA crewmember with any external hardware that exceeds the touch temperature limits could result in damage to the suit and injury or even loss of crew. For hot surfaces, the pain threshold is usually reached prior to any physical injury to the crew. Cold extremes are more difficult to control operationally since the crew's hands and feet become numb prior to damage from frostbite or other cold-related injuries. In fact, at least one crewmember has suffered frostbite due to holding onto cold hardware too long.

All repair and inspection tools were thermally assessed to determine its use created a hazardous thermal extreme. In all cases, either the tools stayed within the allowed -80°F to +150°F (-63°C to 65°C) range for continuous contact, or were analyzed further. Further analysis confirmed that these tools had the correct thermal properties to stay within allowable limits for the time necessary to perform the tasks with the use of EVA glove heaters. Additionally, thermal analysis was performed to ensure that EMU glove contact with the tile and RCC panels would not result in a hazard. These analyses resulted in a warning to the crew to avoid prolonged contact with the RCC panels, as such contact will exceed the glove design limits in certain thermal profiles and cause critical damage.

2.3. Molten Metal

The OBSS is designed to be able to receive power from the Orbiter both when docked in the payload bay and when attached to the SRMS. This power is used both to run the sensors at the end of the OBSS, and to keep heater power to the sensors on the end of the OBSS. Therefore it has electrical connectors in two locations on the OBSS. When docked in the payload bay, the connector for attachment to the SRMS (EFGF connector) is exposed. When connected to the SRMS, the connector for attachment to the Orbiter, referred to as the Manipulator positioning mechanism (MPM)/OBSS saddle contacts, will be exposed. Neither connector was designed to be covered when not in use. As it is unknown until the location of the damage is determined which EVA worksite platform will be used, both exposed connectors must be considered for the potential of molten metal generation. Additionally, there are some connectors in the payload bay used for power to payloads that should be considered, although these are mission specific potential hazards. Any exposed connector with the potential for fault current over 3Amps is a potential generator of molten metal, if a tool comes into contact with a powered pin and a return pin or ground. Considering the 100% oxygen environment inside the EMU, molten metal is a catastrophic hazard.

The MPM/OBSS saddle contacts leaves both sides exposed if the OBSS is attached to the SRMS. Both the connector contacts on the OBSS (OBSS Saddle contacts) and the connector contacts on the MPM (MPM saddle contacts) are exposed. Although the voltage provided by the MPM is less than 32V, the fault current is well over 3 Amps, and as such is definitely a concern for molten metal generation. Ideally, for a catastrophic hazard potential, two-fault tolerance would be in place. Due to the fact that the OBSS is cannot receive power from that circuit when unberthed from the MPM, the power to the MPM saddle contacts are removed. It would take two faults to provide power to the MPM contacts, followed by conductive material contacting the power and return contacts, for molten metal to be generated. Since the MPM has been identified as a no contact area due to concerns with damaging the hardware, the crew will already be avoiding this area, and will therefore have even less of likelihood that tools will be able to reach the slightly recessed contacts.

The OBSS saddle contacts are exposed as well, and are also fairly close to the location at which the crew installs their safety tether. The concern is that a fault will occur, resulting in power flowing backwards to the nominal flow. Fortunately, the OBSS has been designed with protective circuitry which restricts the potential reverse current to much less than 3 amps with one failure. This would mean that after two failures, an off-nominal event of a metallic object touching the contacts would have to occur for the hazard to result. This risk was deemed acceptable considering the contacts are flat, not proud, and that the chance of generation of molten metal decreases with the surface area contacted.

Should the EVA worksite platform be the SRMS, the OBSS may be berthed in the MPMs in the payload bay. In this case, the potential for molten metal generation due to the exposed EFGF connector should be assessed. The EVA crew may be able to avoid coming closer than 3 feet to the connector, in which case the EVA tools would stay far enough away not to contact the EFGF pins. The area of concern for contact is also not very large, decreasing the risk of contact. Should the EVA crew need to translate nearer than 3 feet to the connector, the OBSS sensors can withstand at least the fifteen minutes of no heater power necessary to remove power from the OBSS, removing the chance of reverse current through the EFGF connector due to metal contacting a power pin and a return pin or ground.

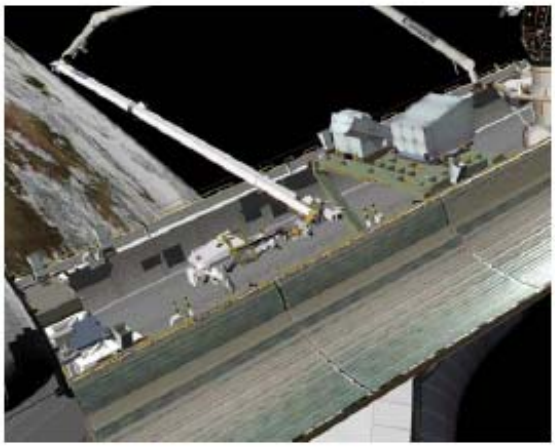


Figure 4. SRMS/OBSS Ingress position[2]

Additionally, there are connectors in the shuttle payload bay that are used to power hardware that is transported in the payload bay and needs to remain thermally conditioned. If that hardware is removed from the payload bay prior to the inspection or repair EVA, then the connector may be exposed. Due to the design of the power lines in the Orbiter payload bay, it is possible to have a connector on the same circuit as that powering the OBSS sensors heaters. During the STS-121 DTO, the Remotely Operated Electrical Umbilical (ROEU) connector was exposed during the EVA. For nominal operations, the ROEU has less than 32V on some pins, and one inhibit to providing more than twice that to other pins. The potential fault current in both cases is over the 3Amp minimum necessary for molten metal generation. Unfortunately, the ROEU connector was on the same circuit as the LCS heater power. The crew also had to come closer than one foot to this connector for set-up of the APFR onto the OBSS. Therefore, a thermal analysis was performed to ascertain if the time needed to set-up the APFR caused the LCS to cool below thermally acceptable limits. Since that analysis was favourable, the ROEU and LCS circuits were inhibited, with three separate electrical inhibits, during that EVA operation. Inhibits in this case are defined as a break in the circuitry, such as a circuit breaker or switch. Should the need arise for performing an inspection or repair on a future flight with an exposed ROEU connector, a flight specific analysis would have to be performed to ensure the LCS thermal profile still allowed sufficient time for OBSS set-up to be performed.

Due to the fact that three inhibits are not in place for all the potential causes of molten metal generation, the program has identified this as an accepted risk. However, with the necessity of contacting a small surface area for the hazard to exist, this risk is considered remote.

2.4. EMU Contamination

The EMU material may be contaminated by hazardous materials, resulting in loss of pressure barrier, changes in thermal emittance properties, or visor occlusion. The sources of contamination assessed for TPS inspection and repair are damaged tile and RCC, and repair materials.

The tile, RCC, and repair materials were assessed to verify materials compatibility with the EMU. The tile and RCC were assessed as not being a hazard to the EMU surfaces. NOAX impacts the glove thermal properties, but only to the extent of effecting the emittance properties of the glove, making the gloves less able to handle high temperature environments. NOAX, STA-54, and Emittance Wash may occlude the visor, however cleaning procedures have been established to preclude long-term damage of the visor. Prior to return to the habitable environment, the crew would have to confirm that no material is being returned.

3. Crew Hazards

Next, hazards to the crew themselves should be examined. These hazards may be affected by hazards to the EMU, or may be completely unrelated.

3.1. Electrical shock

In the case of electrical shock, the causes of potential electrical shock during EVA TPS Inspection and repair are already identified as molten metal concerns. Any potential molten metal concern is also an electrical shock hazard if the potential voltage is greater than 32V. In the case of the MPM saddle contacts and the OBSS saddle contacts, the voltage is never greater than 28V and is therefore not a concern for electrical shock. In the case of the ROEU connector, there is potential for voltage significantly greater than 32V and is therefore a potential electrical shock hazard. However, to control for molten metal, it was already determined that power

would be inhibited to the ROEU connector when the crew was in the area, so this hazard has already been assessed as adequately controlled.

3.2. Lasers

There are two sensors at the end of the OBSS that expose the EVA crew to potential eye hazards, the aforementioned LCS and LDRI. Since both these sensors utilize laser radiation, they were assessed for potential hazard to the crew. Both the LCS and LDRI lasers are considered hazardous due to the ability to cause eye damage. In fact, both are identified as Class 3b lasers or greater. Although it is possible that the LDRI and LCS will be unable to receive power other scenarios are possible that would leave power available to the sensors and still require EVA inspection or repair of TPS. Therefore, the assumption is that laser power is potentially present to harm the crew.

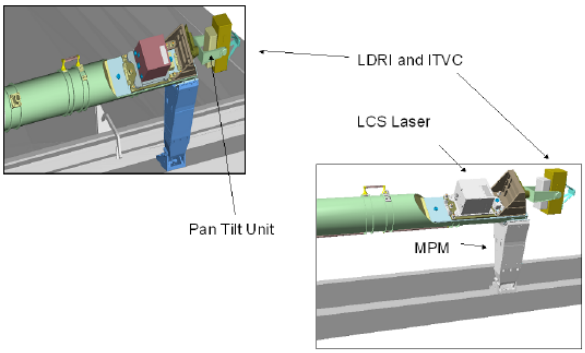


Figure 5. Inspection Sensors

The LCS has a significantly larger nominal hazard zone (NHZ) than the LDRI. Both the LCS and LDRI NHZ had initially been identified as EVA keep-out zones (KOZs) for EVA activities when the OBSS is attached to the SRMS. When the OBSS is berthed in the MPMs in the Orbiter payload bay, it is possible for the laser circuitry to receive power. However, while preparing for the STS-121 OBSS DTO, the EVA operations and training personnel identified a concern that the crew could not avoid these KOZs and still set-up the APFR and ingress the OBSS.

When the LDRI was assessed for this concern, it was identified that the LDRI has software that can place the LDRI in a heater only mode that does not expose the crew to the laser hazard. Next, simulations were assessed using the Dynamic Ubiquitous Orbiter Graphics (DOUG) software to ensure that it is possible to point the LDRI using the pan/tilt unit on which it is mounted to direct the KOZ to a location the crew could avoid. Finally, it was determined that the ability to command the LDRI could be configured such that it required more than one crew action to either move the LDRI KOZ or to change to mode of the LDRI from heaters only to lasing. Finally, it was confirmed by the manufacturer of the LDRI that more than one failure was required to change modes as well. For any future EVA TPS repair or inspection, these same actions of pointing the LDRI, and putting it in the heaters only mode would have to be performed.

For the LCS, a slightly different approach was taken. The LCS is not mounted on a pan tilt unit, and therefore the KOZ for the LCS is not as maneuverable with respect to the OBSS ingress location. After examining the LCS KOZ with the DOUG software, it was determined that the LCS KOPZ was only unavoidable during ingress and egress from the OBSS in the payload bay. Since the LCS and ROEU connector were on the same circuit for STS-121, the LCS was already being inhibited with three separate inhibits during OBSS ingress, as the location and time of concern for the ROEU molten metal and shock hazard was also OBSS ingress. It is important to note that the location of the LCS KOZ makes it impossible for the crewmember actually on the OBSS to be exposed to the laser hazard. Additionally, should an EVA repair or inspection task be necessary on a future flight, the thermal analysis performed to ensure no damage to the LCS hardware would need to be reassessed with flight specific information.

3.3. Contamination from Thrusters Firings

Due to the fact that a TPS inspection or repair EVA would require the crew to be outside the Orbiter payload bay, the EVA crew would have the potential to be near Orbiter thrusters, depending on the location of the damage. Proximity to the thrusters exposes the EVA crew to the potential for exposure to hydrazine, which is a hazardous substance. Should the damage location place the EVA crew in proximity to thrusters, the thrusters will be inhibited from firing. These inhibits would also be in place should the EVA crew be translating near the thrusters on the SRMS/OBSS. Due to the fact that there are only two inhibits present for prevention of thrusters' firings, and failures have been identified which may overcome these inhibits, additional measure for exposure to hydrazine have been identified. Should the EVA crew be contaminated by hydrazine, it is possible to remain in the EVA environment and 'bake-out' the hydrazine. This method has been analyzed to require no more than 30 minutes of bake-out time, and can be performed with the EVA crew connected to airlock consumables if necessary.

3.4. Detached Crew

The potential of detached EVA crew must also be addressed in an EVA inspection or repair scenario. The potential causes of detached crew are a failure of the EVA safety tether, failure of the structure to which the

EVA tether is attached, or the inadvertent release of the OBSS from the SRMS.

The EVA safety tether is two-fault tolerant to failure of the hook. The EVA safety tether is also design to withstand the load of an EVA crewmember coming loose from structure at the nominal rate of translation with a safety factor without failing. Additionally, the EVA safety tether is designed with a breakaway function which will slow the crewmember down before he reaches the end of the tether, reducing the load to underlying structure.

The underlying structure that the EVA safety tether is attached to is also designed to withstand the load of an EVA crewmember coming loose at a nominal translation rate times a safety factor. The crew is also trained to which structure the safety tether can be attached. In the case of performing an inspection or repair EVA off the Boom, the safety tether is attached to the handrail on the end of the SRMS prior to the crew ingressing the APFR on the mid-point or tip of the OBSS.

Finally, there is the concern with inadvertent release of the OBSS from the SRMS. Initially, the SRMS was assessed as a single mechanical failure away from losing the OBSS. However, an assessment was performed prior to the STS-121 DTO that confirmed the SRMS has a design for minimum risk mechanism that is equivalent to single-fault tolerance for failure. This assessment was performed with analyzed EVA load cases, which were subsequently confirmed to envelope the EVA load cases observed on the STS-121 DTO. In addition, the mission operations directorate performed test in the Neutral Buoyancy Lab (NBL) that confirmed the EVA crew could easily get out of the APFR. Should the OBSS be released, the crew would quickly egress the APFR, and use the safety tether to return to structure. If the safety tether were to become snarled with the OBSS, the EVA crew could release the safety tether and use the SAFER to return to structure. Due to the fact that the last two options for controlling these hazards are difficult to verify in a robust manner, this hazards was again considered a remote likelihood, and therefore classified as an accepted risk by the shuttle program.

In addition to the aforementioned causes for loss of EVA crew, there is also the potential for inadvertent jettison of the SRMS with the OBSS and EVA crew attached. This hazard is controlled by the use of three inhibits. All three are verified to be in the proper position to prevent SRMS jettison prior to the start of EVA operations.

3.5. Ability of Crew to Return

The ability of the crew to safely return to the habitable volume in a contingency situation that also needs to be addressed. Both the EMU and the SRMS/SSRMS have single point failures that be considered for this question, as we must be able to withstand and failure and still return the crew safely.

In the case of the EMU, it is possible for a single failure to result in a loss of cooling, or for a puncture in the suit to occur. This results in a need to utilize the secondary oxygen supply, resulting in a nominal 30 minute time limit for return to the habitable environment. If the location is far enough aft on the Orbiter belly, it is not possible with SRMS and translation time to reach the airlock in less than thirty minutes. However, 30 minutes is the nominal time limit. In an effort to mitigate this risk, it was determined that EVA tasks in the location of risk would occur early in the EVA timeline, so that extra oxygen would be available in the primary oxygen tanks. Also, the nominal amount of oxygen in the secondary oxygen pack is actually lower than the total possible amount of oxygen. Depending on the time since the secondary oxygen pack was filled there may be additional oxygen. This would give additional time for the crew to return. Also, the vent used for cooling failures is the larger sized vent, and while the crew is being moved by the SRMS/OBSS, it is possible to sue the smaller helmet vent as the crew is not building up as much heat due to activity. Overall, it will need to be a real-time assessment based on damage location and the amount of oxygen in the secondary and primary tanks.

The SRMS may fail in such a way that single joints may not move or the entire SRMS may not move. If the failure is only a single joint failure, the SRMS software and crew training ensure it is possible for the crew to return to structure with the remaining joints. Should all the SRMS joints fail, the crew is able to translate down the OBSS/SRMS and return to structure. More than a single failure would have to occur for all RMS joints to fail. This is also true if the EVA worksite platform is the SSRMS, or the SRMS without the OBSS.

4. Orbiter Hazards

In addition to hazards to the EMU and crew, hazards to the Orbiter must be considered. The likelihood and consequences of hazards to the Orbiter are exacerbated by the proximity to the Orbiter TPS necessary.

4.1. Structural Failure of OBSS

Structural failure of the OBSS while the EVA crew is attached to the OBSS would be a hazard to the crew as well as to the Orbiter. However, the proximity of the

OBSS to the Orbiter TPS means that the structural failure of the OBSS would result in the loss of the Orbiter as a whole. Additionally, there is some chance that the structural failure of the OBSS might result in damage to the ISS as well.

With the exception of kick-loads, the manufacturer of the OBSS has indicated that all anticipated design loads are within structural design limits, and positive margins are preserved. The EVA loads used in this analysis were reached by analysis, then confirmed to be enveloped by the STS-121 DTO observed loads.

In the case of EVA kick-loads, the composite structure of the Boom did not meet the required 125 ftlb load.[3] Due to the nature of the composite material, the manufacturer was not able to completely identify how the Boom would fail if the inadvertent load was applied, only that the structural analysis confirmed 125 ft/lbs exceeded the allowable loads. As a result, the crew was trained to avoid contact with the composite structure. In the case of an EVA task to inspect or repair TPS from the Boom mid-point or tip, the operations personnel and crew were confident that the composite material would not be inadvertently contacted. As the only control for this hazard is an operational control, the hazard was identified as remote likelihood an accepted by the shuttle program as an accepted risk.

4.2. Loss of control of OBSS/SRMS

The loss of control of the SRMS/OBSS would in the worst case result in collision of the SRMS/OBSS with the Orbiter. Potentially, it could also result in collision between the EVA crew and the Orbiter, resulting in loss of crew and catastrophic damage to the Orbiter. Loss of control could potentially be caused by excessive EVA loads and flexibility of the SRMS/OBSS or by software failure or incorrect IVA crew commanding.

The flexibility of the OBSS/SRMS was assessed during the STS-121 DTO. Prior to the DTO, the EVA crew were trained to minimize EVA loads into the boom by reacting loads during APFR installation, reconfiguration, ingress and egress, performing tool/bag reconfiguration prior to Boom ingress and avoiding harsh or sudden body movement while on the boom. These constraints remain in place for any future TPS EVA tasks. In addition, prior to the DTO, the crew was trained to only ingress the APFR at the Orbiter sill, and to perform real-time APFR reconfiguration at the Orbiter sill, as well as having the second crewmember hold the Orbiter sill and boom for stabilization during these operations. The STS-121 DTO confirmed that the OBSS was slightly less flexible than anticipated by analysis, as well as that the SRMS/OBSS were an acceptable platform for the majority of EVA inspection and repair operations. For this reason, the constraints regarding APFR ingress/egress away from the sill were deemed unnecessary. In fact, the initial expected EVA loads necessary to perform repair tasks were such that the SRMS brake slip either didn't occur or would change the position of the tip of the boom less than 5 feet in any direction. Since the tip of the Boom will remain further than 5 feet form the Orbiter, this precludes collision.

The SRMS is designed to prevent runaway due to software failures at such a rate of speed that corrective action cannot be taken. The rate of speed of the SRMS is determined by how close the SRMS is to structure. Vernier rates, which are the slower rates, are used when the SRMS is close enough to structure that the crew has sufficient time to react and either change or stop the motion of the arm. In addition, these rates are slow enough for the EVA crew to perform avoidance maneuvers such as a layback, if necessary.

Due to the fact that operational controls are necessary to avoid this hazard, loss of control of the SRMS was recognized as a remote likelihood event and accepted as a risk by the shuttle program.

4.3. Loose EVA Tools

The effects of loose EVA tools during a TPS inspection or repair EVA task range from possible loss of Orbiter from catastrophic damage to the TPS to loss of EVA crewmember from damage to the EMU. EVA tools designed to support inspection or repair are stored in individual caddies or are restrained in tool bags when not in use. When removed from these caddies or bags, the tools are required to be tethered at all times. These tethers are provided to protect against inadvertent release of the tools by the EVA crew. In addition, for repairs where several tools are necessary, one crewmember will be acting as a tool tender, handing off tools to the crewmember performing the repair, such that the crewmember closest to the TPS will not be responsible for managing the tools.

In addition to loose EVA tools used directly for inspection or repair, a slack safety tether may snag or lash against TPS or other critical Orbiter hardware with resultant damage to TPS and loss of vehicle. The tether is designed such that it auto-retracts to maintain tension. The crew is trained to configure the tether properly such that adequate tension is maintained.

Due to the fact that the only controls in place while the tools are being used are operational in nature and that tether operation also requires operational controls, this hazard is considered a remote likelihood.

4.4. Collision of EMU with Orbiter TPS

Collision of the EMU, particularly the helmet, could result in damage to the Orbiter TPS beyond that which was already present. The stability of the worksite platform, specifically the OBSS/SRMS which was verified during the STS-121 DTO, impacts the risk of this hazard occurring. Considering that the STS-121 DTO verified that the OBSS/SRMS platform was sufficiently stable to handle the majority of repair and all inspection tasks without moving the crewmember more than 5 feet, the likelihood of this hazard has decreased.

Prior to the STS-114 gap-filler removal, testing was performed to envelope the risk of damage to the TPS due to EMU impact. This testing only addressed tile impact, not RCC impact. The analysis was performed to test for helmet impact into tile at various "heads down" angles in an effort to determine the force needed to damage tile. At the highest force credible catastrophic damage to tile did not result. RCC damage due to helmet impact has not yet been assessed and would need to be addressed real-time prior to an EVA repair. Prior to that assessment, the assumption is that damage is possible and can only be controlled by situational awareness of the EVA crew and SRMS operator. As such, this is currently a remote likelihood hazard, and has been accepted by the program.

5. Conclusion

While several hazards have been identified for an EVA inspection or repair of TPS, these hazards have been documented and brought to the Shuttle and ISS programs. Should a real-time need for a TPS repair occur, these hazards will be assessed and weighed against the consequences and risks of not performing a repair. In the case of a real-time event several of these hazards would need to be re-assessed to ensure valid controls are still in place, but with the work performed prior to STS-114 and STS-121 the controls are already identified and therefore much easier to validate. In addition, this work assisted in determining what training the EVA crew would need to be prepared to perform a contingency EVA TPS repair.

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3. C. Arnoldi, IBA090000, "Structural Failure"
4. K. Shook, STS-121 OBSS DTO Laser Inhibits, March 7, 2006.



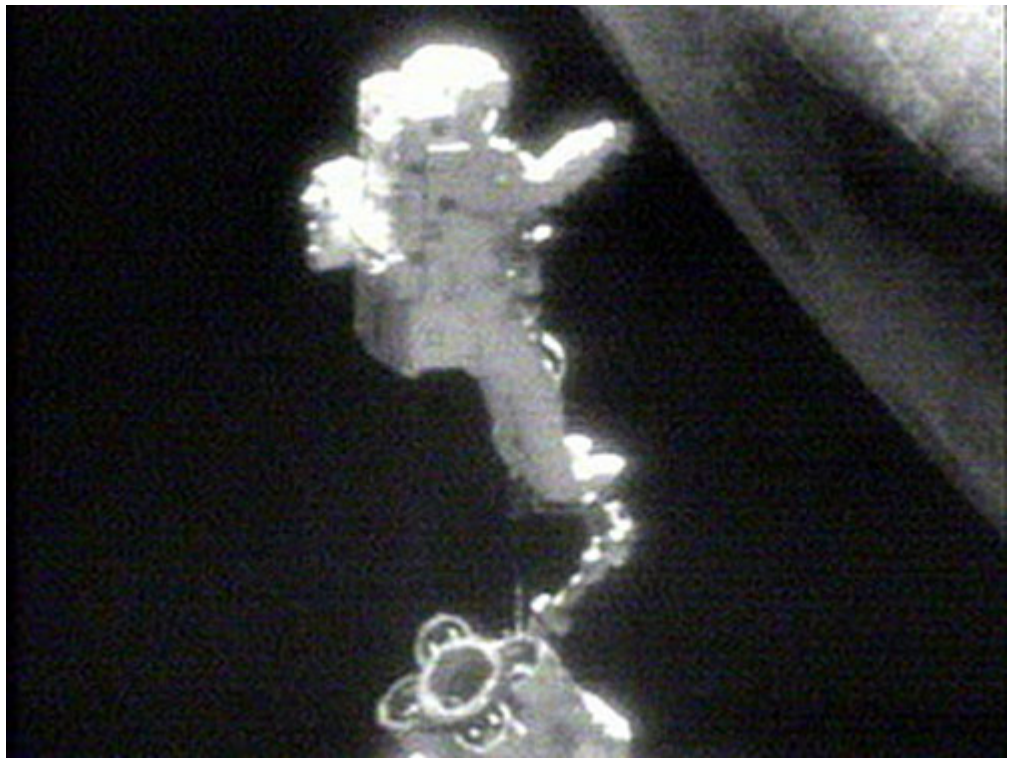
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EVA HAZARDS DUE TO TPS INSPECTION AND REPAIR

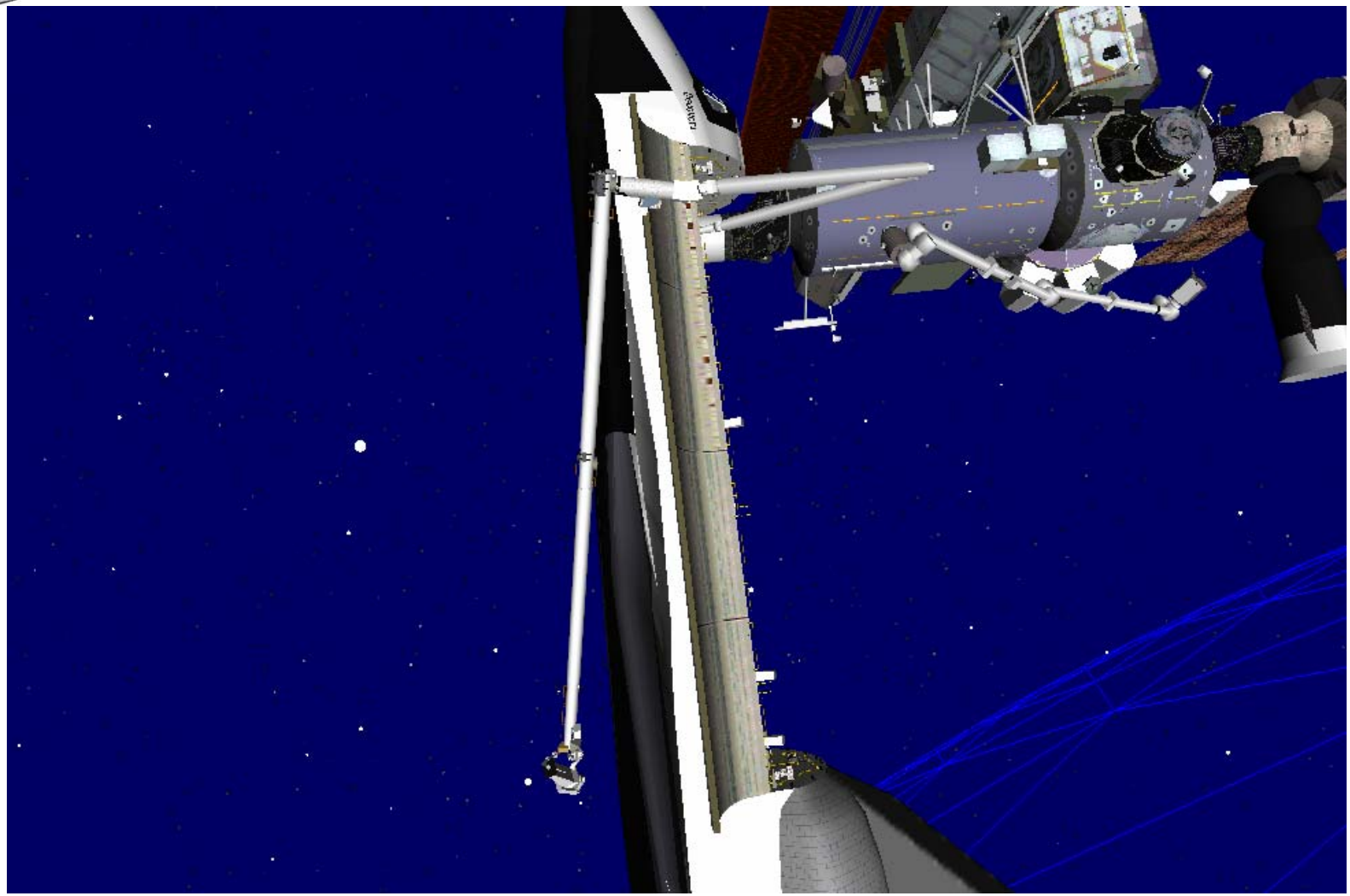
Christine Stewart
SAIC
May 14, 2007

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TPS Inspection and Repair



EVA TPS Inspection

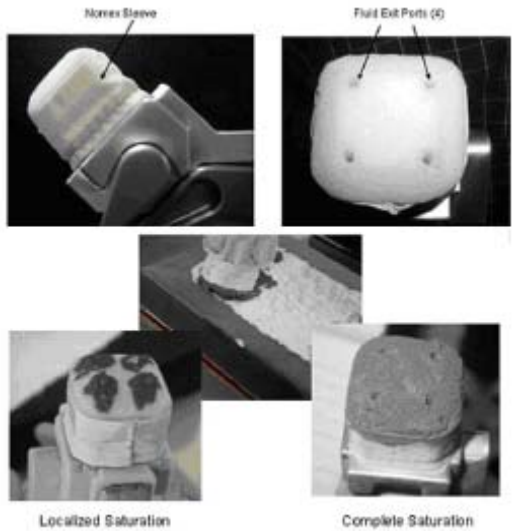
- TPS Inspection is not nominally performed EVA
 - Ground/Orbiter cameras
 - OBSS Sensors
 - Laser Dynamic Range Imager (LDRI)
 - Laser Camera System (LCS)
 - Intensified Television Camera (ITVC)
 - Rendezvous Pitch Maneuver



- If failures occur
 - MMT may direct EVA inspection
- EVA Inspection from SRMS/OBSS, SRMS, SSRMS
 - EVA cameras
 - 3 point inspections
 - WLE mapping

TPS Repair

- TPS Repair
 - Only option is to perform repair EVA
- Worksite platform
 - Depends on location
 - SRMS or SSRMS if forward
 - SRMS/OBSS if aft
- Several different repair methods
 - Tile
 - Shuttle Tile Ablator (STA)-54
 - Emittance Wash
 - Tile Overlay
 - RCC
 - NOAX
 - RCC Plug



Emittance Wash Applicator

EMU Hazards

- Sharp Edges
- Touch Temperature
- Molten Metal
- EMU contamination

EMU hazards

- Sharp Edges
 - Hazard:
 - Also known as suit puncture, includes sharp edges, burrs, corners, etc.
 - Any puncture to the suit greater than ¼- inch would result in loss of crew
 - back-up oxygen and contingency planning sized for ¼ inch hole
 - All inspection and repair tools nominally designed and verified to meet EVA sharp edge requirements
 - Some hardware identified as “no touch”
 - LDRI baffle
 - Electrical flight-releasable grapple fixture (EFGF) grapple release
 - Grapple fixture cam arms
 - Damaged RCC and Tile
 - Verified to break or yield prior to damage to EMU

EMU Hazards

- Touch Temperature
 - Hazard:
 - Cold and hot extremes may damage the suit or cause injury to the crew
 - Pain threshold for hot temperatures is reached prior to suit damage – must be able to let go
 - Cold extremes numb the crew, frostbite results
 - All Inspection and Repair tools analyzed
 - Most inspection tools met the -80°F to +150°F (-63°C to 65°C)
 - Remainder of tools within allowable grasp times to perform task
 - RCC panels and Tile analyzed
 - RCC panels can exceed glove limits if contacted for greater than 30 seconds
 - Tile not an issue

EMU Hazards

- Molten Metal
 - Hazard:
 - Exposed energized surfaces with potential fault current and voltage greater than 32V and 3A may generate molten metal
 - 100% oxygen environment inside EMU – catastrophic hazard
 - Several exposed connectors of concern
 - MPM Saddle connector
 - OBSS Saddle contacts
 - EFGF connector
 - ROEU connector

EMU Hazards

- Molten Metal (cont.)
 - MPM saddle connector
 - Voltage less than 32V
 - Fault current greater than 3 Amps
 - Remove power from MPM after OBSS is unberthed
 - OBSS Saddle contacts
 - Voltage less than 32V
 - Protective circuitry restricts current less than 1 Amp
 - Contacts flat
 - EFGF connector
 - OBSS berthed in MPMs
 - Remove power to the OBSS
 - ROEU connector
 - Crew needs to translate within 1 foot
 - Three inhibits to remove power to ROEU

EMU Hazards

- EMU contamination
 - Hazard:
 - Pressure barrier violations
 - Staining the suit
 - Visor occlusion
 - RCC & Tile
 - No hazard to EMU surfaces
 - NOAX
 - Impacts emittance properties of the EMU glove
 - NOAX, Emittance Wash, STA-54
 - May obscure visor
 - Procedures in place to prevent permanent damage of the visor

Crew Hazards

- Electrical shock
- Lasers
- Contamination from Thrusters
- Detachment of crew
- Ability of Crew to Return

Crew Hazards

- Lasers
 - Hazard:
 - Potential eye injury/blindness
 - LDRI
 - Class 3b laser
 - Directed away from path of crew
 - Heaters only, non-lasing mode
 - LCS
 - Large NHZ – impossible for EVA crew to avoid KOZ during set-up
 - 3 electrical inhibits to powering LCS when crew in KOZ

Crew Hazards

- Contamination from thrusters
 - Hazard:
 - Hydrazine is a toxic substance
 - Thrusters are inhibited
 - Prior to EVA near thrusters inhibits are confirmed

Crew Hazards

- Detachment of crew
 - Hazard:
 - Loss of crew due to detachment from structure
 - Safety tethers
 - Hooks two-fault tolerant, tether DFMR
 - Tethered to SRMS handrail
 - Inadvertent release of OBSS
 - Inadvertent jettison of SRMS
 - SAFER

Crew Hazards

- Ability of crew to return
 - Hazard:
 - Crew doesn't return to airlock prior to use of consumables
 - 30 minute return time
 - Achievable from majority of locations
 - From farther locations may use smaller vent, allowing crew to return before use of oxygen

Orbiter Hazards

- Structural Failure of OBSS
- Loss of control of OBSS/SRMS
- Loose EVA Tools
- Collision of EMU with Orbiter TPS

Orbiter Hazards

- Structural Failure of OBSS
 - Hazard:
 - Catastrophic damage to the Orbiter
 - OBSS meets structural loads
 - With exception of inadvertent kick-loads
 - Composite material keep-out zone for crew
- Loss of control of OBSS/SRMS
 - Hazard:
 - Catastrophic damage to the Orbiter
 - STS-121 DTO confirmed OBSS/SRMS sufficiently stable
 - 5 feet away from TPS for crew reaction time

Orbiter Hazards

- Loose EVA Tools
 - Hazard:
 - Catastrophic damage to the Orbiter TPS
 - Tools are contained in individual caddies
 - When in use tools are tethered
- Collision of EMU with Orbiter TPS
 - Hazard:
 - Catastrophic damage to the Orbiter TPS
 - Testing confirmed EMU helmet causes only minimal damage to tile
 - STS-121 DTO demonstrated decreased risk of EMU collision

Conclusion

- Hazards for EVA TPS Inspection and Repair have been identified and controls identified
- This assessment will assist program management in performing the risk trade assessment should Orbiter TPS damage be identified in the future

Questions?

